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TEXTILE SERIES - REPORT NO. 85

ABRASION DAMAGE OF TEXTILE FIBERS

by

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OFFICE OF THE QUARTERMASTER GENERAL

Office of The Quartermaster General
Research and Development Division
Textiles, Clothing and Footwear Branch

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FOREWORD

Although much emphasis is placed in the Quartermaster research program on field tests to indicate the functional performance of military fabrics, it is recognized that the evaluation of such wear tests is difficult without sufficient knowledge of the fundamental properties of textile fibers. No doubt a correlation between fiber properties and fiber performance in service is very complex and at present no man alive can predict exactly how a textile material will behave in end use. This is partly due to the fact that the fiber properties critical in service are not sufficiently known.

To overcome this situation a systematic study of unknown or inadequately known fiber properties is carried out in the Textile and Leather Division of the Quartermaster Research and Development Laboratories. This investigation has recently been extended to the abrasion of textile fibers.

Attrition is a major cause of wear in textiles although by no means the only one. Mechanical deterioration in service is usually the result of frequently repeated actions which are normally separated from each other by rest periods. Such deterioration occurs under a wide variety of conditions. It is almost impossible in laboratory tests to duplicate all the conditions occurring in service, nevertheless a fairly good correlation exists between laboratory abrasion tests on fabrics and wear tests.

The overwhelming majority of abrasion tests are performed on fabrics. They are greatly influenced by the weave, texture, and finish and, therefore, they reflect only in part the inherent abrasion resistance of the fiber material itself.

Abrasion tests were performed in this study on yarns where the influence of form factors is not so serious. A new testing and evaluation method was developed for using the Stoll-Quartermaster abrasion tester described in Textile Series Report No. 54.

Twenty-seven yarns were tested in the form of multi-filaments and staple yarns representing almost all types of available textile materials. Much greater differences were observed in the inherent abrasion damage of these fibers than would be expected from the differences in their tensile tenacity.

Inherent abrasion damage is a new criterion for evaluating the functional performance of textile fibers and can also be used conveniently to investigate all the factors in yarns which influence the resistance to abrasion of fabrics.

The experimental work described in this paper was performed by Mr. W. Zagieboylo, the figures were prepared by Mr. J. Medernach, and editorial review of the paper was made by Mr. N. E. Roberts.

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ABSTRACT

The inherent abrasion behavior of 14 different textile materials in the form of yarns was investigated and expressed by the abrasion damage,which is the opposite of abrasion resistance. This was measured quantitatively by the fiber fineness (grex) destroyed in flexing around a steel bar under standardized conditions using the Stoll-Quartermaster abrasion tester. The abrasion damages were evaluated relative to that of high-tenacity nylon multifilaments. Great differences exist in the abrasion behavior of various textile fibers. The damage of multifilaments increases from nylon to Dacron polyester fiber, viscose, Fortisan, Orlon acrylic fiber, Saran, silk, acetate, and casein, while that of staple yarns increases from nylon to Dacron polyester fiber, cotton, Fibravyl, Dynel, Kuralon, Thermovyl, wool, Orlon acrylic fiber, viscose, and acetate. Staple yarns were always more abraded than corresponding multifilaments. Although high elastic energy of fibers is the main factor preventing inherent abrasion damages, extensibility, yarn surface and friction must also be taken into account in interpreting the abrasion behavior of various textile fibers.

INTRODUCTION

When textiles in contact with solid bodies are moved relative to each other, rubbing-off or abrasion occurs. The abrading substance can be another textile or materials such as metals, glass, leather, plastics, dirt, grit. The abrasion is a result of deformations due to compression, tension, bending, shear, and also of cutting. These and other factors cause the gradual damage of textiles in service. It is known that abrasion is a major contributing factor to wear. Kaswell emphasized recently in his excellent monograph, "Textile Fibers, Yarns and Fabrics," that a clear distinction should be made between abrasion and wear.[6]

For any critical judgment of the potentialities of textile materials, quantitative data on their abrasion behavior is as necessary as data on their tenacity, extensibility, elastic recovery, etc. The majority of abrasion tests of textiles has been carried out on fabrics, and they reflect only in part the abrasive behavior of the fiber material itself, since the attrition is markedly influenced here by the fabric weave, texture, and finish. Although the abrasion of yarns is also affected by form factors (yarn size, structure, twist), their influence can be greatly reduced if differences in the samples tested are kept within reasonable limits. Tests performed on multifilamentous yarns with low twist reflect mainly the abrasion of the material itself. In staple yarns, however, the yarn structure and surface affect the abrasive behavior. The yarns selected for testing were without special finishes and they did not differ greatly in form factors if multifilamentous and staple yarns are considered as separate groups.

Not much is known about the inherent abrasive behavior of textile fibers.[6] According to Backer, [3] abrasion resistance decreases from nylon to cotton, wool, viscose, acetate, and casein. This rather qualitative estimation is based on the results of numerous authors obtained between 1932 and 1948 using different types of testers and widely varied fabric and yarn samples. Kay [9] obtained a similar ranking from flex abrasion tests performed on wet fabrics using the Stoll-Quartermaster tester.

In these tests nylon was found to have the highest abrasion
resistance followed by Dacron, Orlon, wool, and cotton, while
viscose and acetate had the lowest resistance. Comparable
quantitative data on the abrasion of different yarns were also
published by Matthes and Keworkian, [7, 8] Hamburger, [4] and
Hicks and Scroggie.[5] Using the Taber tester Hicks and Scroggie
performed tests on yarns as well as on plain weave fabrics, and
they found that the "abrasion life" diminished from nylon to
polyacrylonitrile, viscose, and acetate approximately in the
ratio 1000 : 237 : 165 : 83.

The abrasion of textiles can be measured quantitatively by
the progressively diminishing thickness, by loss of weight,
strength, energy absorption, and by the number (or time) of
reciprocating actions (cycles) to cause a partial or total
failure. Cycle numbers at break is a convenient and frequently
used method of expressing the results of laboratory abrasion
tests, but it is by no means the best method. Such cycle
numbers indicate the abrasion life of a material and they can
be compared for different fibers. It is known, however, that
they are greatly influenced by many details in the testing
procedure. They can be evaluated quantitatively only if
obtained on the same tester under identical conditions using
comparable samples.

The purpose of this study is to investigate quantitatively
the abrasive behavior of various textile materials. The abrasion
of yarns will be compared first on the basis of cycle numbers at
break. An attempt will then be made to measure the inherent
abrasive damage of textile fibers by the yarn grex destroyed.
Abrasion damage is a characteristic opposite of resistance,
and it expresses the substance rubbed off during the test per-
formed. Finally the abrasion damage of various textile fibers
in the form of multifilamentous and staple yarns will be measured
and discussed.

YARN ABRASION

Yarn abrasion can be investigated in testers specially
designed for fibers in which mostly single yarn strands are
abraded. The models developed by Boehringer, Ecker, Jansen,
Mecheels, Matthes (T. H. Aachen tester), Neumann, Oestermann,
Weltzien, Zart, [7, 8, 10, 16, 18] Walker and Olmstead [17]
represent such testers. The abrasion of yarns can also be

measured quantitatively in fabric abrasion testers, in which
a correlation between yarn and fabric abrasion tests is easily
attained. Such a correlation is frequently needed, either when
yarns with known abrasion serve for the construction of fabrids
or when abrasion tests performed on fabrics must be re-checked
and interpreted by the abrasion of warp and filling yarns removed
from the fabric.

The fabric abrasion testers of Schiefer, Stoll, Taber and
Wyzenbeek are the models mostly used in this country at present.
[1, 2] For the Schiefer tester [1, 11] a circular plastic clamp
is provided permitting 54 portions of the same yarn strand to be
abraded simultaneously. In the Taber [5] and Stoll–Quartermaster
[12, 13] testers the fabric sample must be replaced by an assembly
of parallel yarns suitably inserted in the tester. The Taber
tester measures the flat abrasion of yarns against steel either
parallel or perpendicular to the fiber length. Such tests were
carried out by Hamburger [4] and by Hicks and Scroggie.[5]

FLEX ABRASION USING THE STOLL–QUARTERMASTER TESTER

The tests reported in this study were performed on yarn
bundles by flex abrasion using the Stoll–Quartermaster tester.
The yarns were laid parallel in any desired number by a yarn
reel. They were cut in sections of approximately six inches
(15 cm) in length and held together by masking tape placed on
the ends as shown in Figure 1. These two ends were clamped into
the sample holders on the upper (stationary) and lower (reciprocat-
ing) abrasion plates of the tester as shown in Figures 2 and 3.
The yarn bundle itself was folded along a square-edged hardened
steel bar of 2 mm thickness (Figure 4) and inserted under tension
in the tester (Figure 5). In addition, it was kept under the
pressure of the abrasion head. Tension and pressure exerted on
the yarns were controlled and they were varied between 0.5 and
4.5 lb (227-2041 g) to increase or reduce the severity of the
attrition. A constant stroke length of 0.5 in. (1.27 cm)
measured on the folding bar, and a constant stroke speed of 120
cycles (double strokes) per minute was maintained during all the
tests performed.

FIG. 1
YARN BUNDLES

FORTISAN
8 YARNS - 784 Gx

NYLON
27 YARNS - 2997 Gx.

ACETATE
81 YARNS - 8991 Gx.
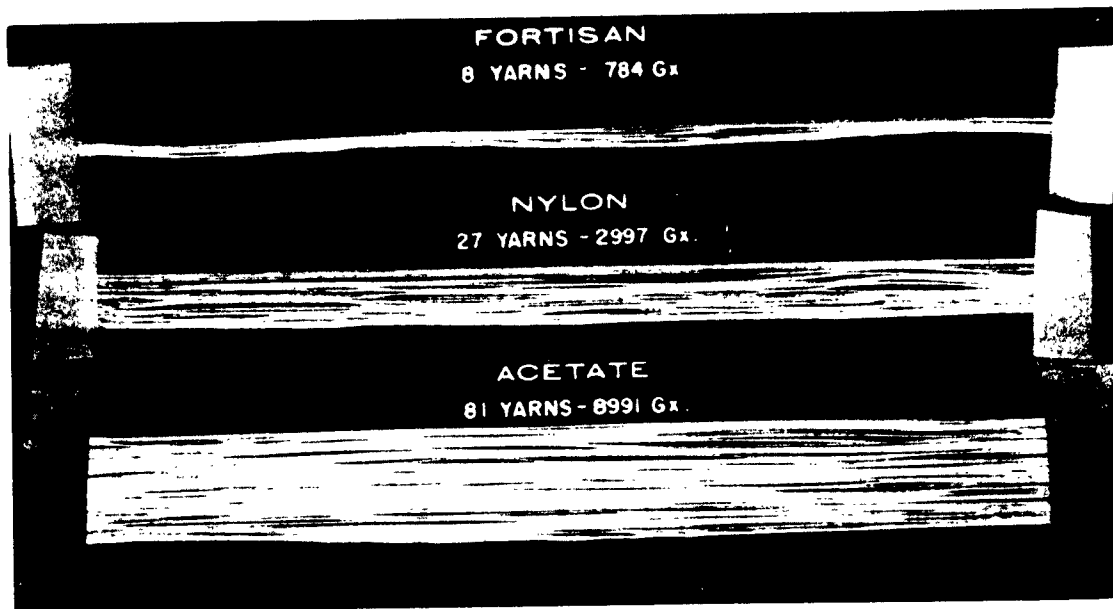
FIG. 2
INSERTION OF THE YARN BUNDLE INTO THE STOLL-QUARTERMASTER TESTER.
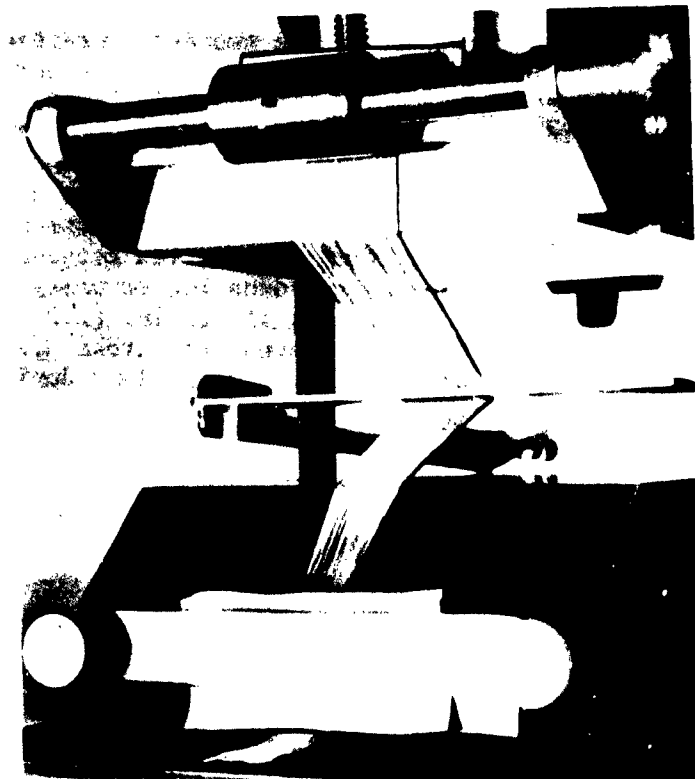
FIG. 3

YARN ABRASION ON THE STOLL-QUARTERMASTER TESTER

OPEN POSITION

PRESSURE LOAD

PRESSURE

UPPER CLAMP

UPPER ABRADING PLATE (STATIONARY)

FOLDING BAR

TENSION

YARN BUNDLE

LOWER ABRADING PLATE (RECIPROCATING)

LOWER CLAMP

TENSIONING LOAD

AUTOMATIC STOP SWITCH

DRIVING MECHANISM   COUNTER   MOTION OF FOLDING BAR   MOTION OF ABRASION TABLE

WORKING POSITION

PRESSURE

TENSION

YARN BUNDLE

FIG. 4.
FOLDING BAR

in. 0   1   2   3   4   5

cm. 0 1 2 3 4 5 6 7 8 9 10 11 12 13

FIG. 5

POSITION OF THE YARN BUNDLE

TENSION   TENSION

YARN BUNDLE

FOLDING BAR

PRESSURE

YARN BUNDLE

TENSION

PRESSURE

TENSION

Abrasion of the yarns by rubbing and flexing took place in the tester as a result of the forward and backward motion of the folding bar. The two rather sharp edges of the bar were perpendicular to the yarn length and they caused the main attrition of the yarn bundle. The lines of highest abrasion moved up and down along the yarn bundle length during each cycle.

Figure 6 demonstrates schematically the position of the yarn bundle and folding bar during various stages of a flex cycle. The most severe attrition occurs on that part of the bundle which was bent and pressed four times around the edges of the folding bar during a full cycle (i.e., around each edge, once in the forward motion and again in the backward motion). This part appears cross-hatched between numbers 3 and 6 on Figure 6B and C, and it is shown greatly diminished in Figure 6D. A minor flex abrasion takes place on the neighboring parts (between numbers 2 and 3, and also between 6 and 7) which passed the edges only twice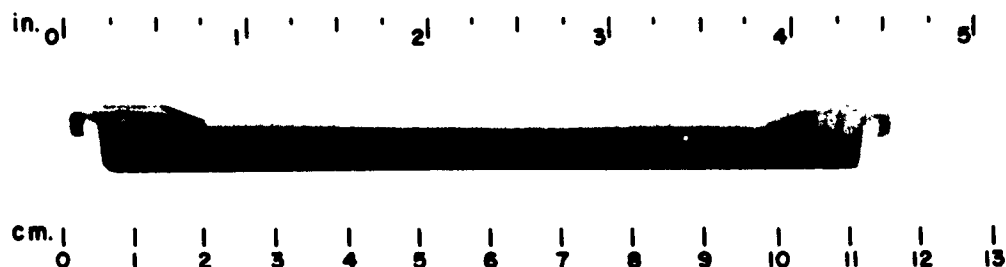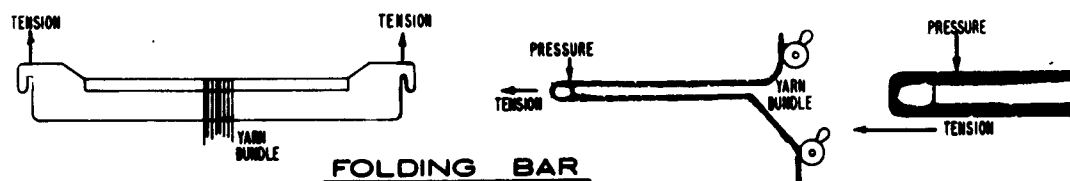 (i.e., passed one edge in the forward and backward motion). The flat abrasion of the yarn bundle by rubbing (between the horizontal surface of the folding bar and the upper or lower plate of the tester, respectively) can be neglected because it is essentially less severe than the abrasion by flexing around the edges of the steel bar. The yarn bundle breaks, of course, on that part where the most severe attrition took place (Figure 6D).

Figure 7 demonstrates the progressive attrition of Fortisan, nylon, and acetate multifilament bundles after one-tenth, one-half, three-quarters, and all of the cycles necessary for their rupture. A permanent deformation (crimp along the folding bar) appears even at the beginning, and rupture of yarns occurs mainly at the end of the flexing procedure. After the rupture of a few yarns the attrition proceeds very rapidly as a result of the increased tension to which the remaining yarns are subjected.* Rupture stopped the reciprocating motion automatically, clearly indicating the end point of total breakdown. All the cycle numbers reported in this study represent mean values of five tests performed under standardized atmospheric conditions, at 70 F (21.1 C) and 65% relative humidity. Consecutive tests were made by the same operator using the same tester and the same folding bar, and they were frequently repeated. This was considered important in view of the fact that reproducibility is a major problem in abrasion tests.

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*This will be discussed in more detail later on page 14.

FIG. 6

SCHEMATIC DEMONSTRATION OF A FLEX CYCLE

POSITION OF YARN BUNDLE IN TESTER

A AT START
B AFTER THE FORWARD MOTION
C AFTER THE BACKWARD MOTION
D AFTER FLEX ABRASION

UNAFFECTED
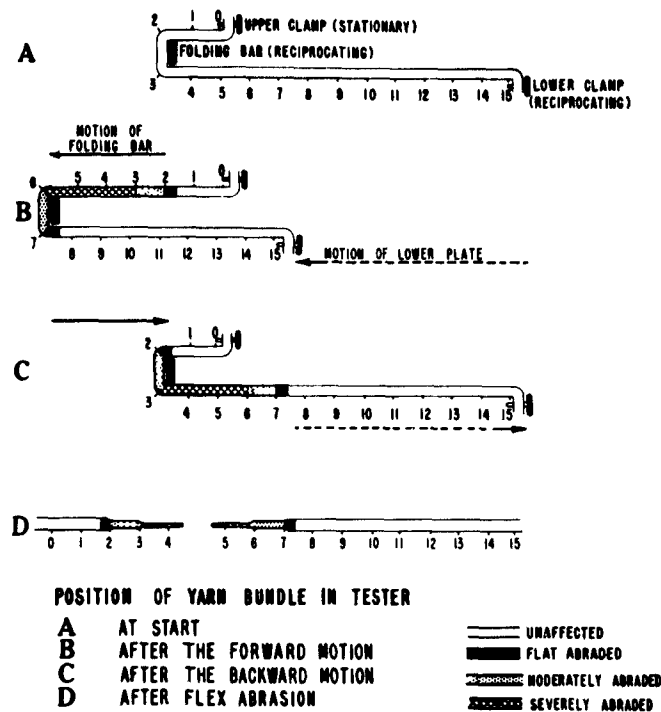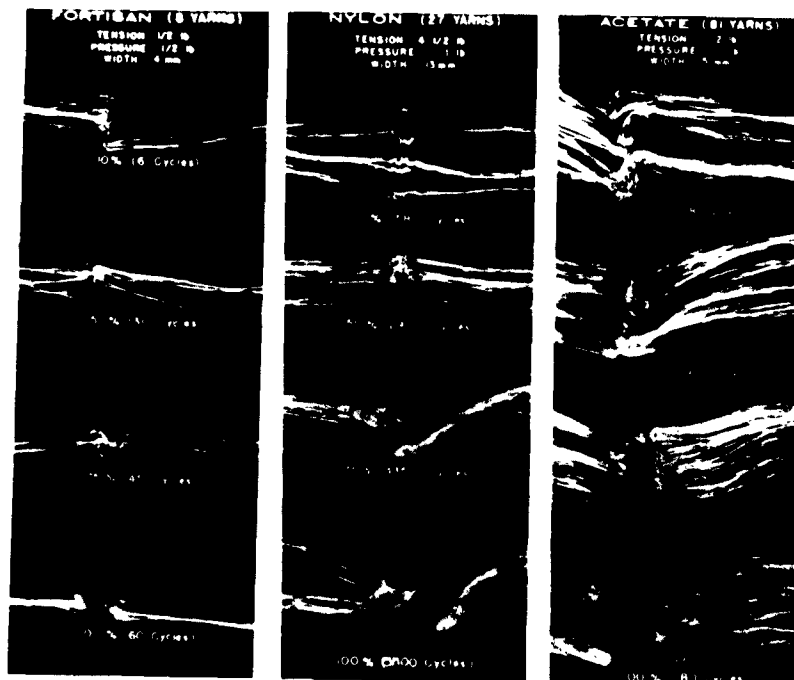FLAT ABRADED
MODERATELY ABRADED
SEVERELY ABRADED

FIG. 7

PROGRESSIVE ATTRITION OF YARN BUNDLES

INFLUENCE OF YARN PRESSURE, TENSION, AND BUNDLE SIZE (GREX)

Yarn bundles consisting of nylon and acetate multifila-
ments with the same form factors were first abraded under
identical testing conditions as shown in Table I. The two
fibers represent extremes with respect to abrasion behavior
since nylon multifilaments have the highest abrasion resistance
of the known textile fibers, while the resistance of acetate is
quite low.

Testing conditions were made identical by subjecting the
acetate first to the same actual tension (0.68 g/gx) and then
to the same relative tension (13-14%) as the nylon without
changing other factors.* A high cycle number, 6199, was obtained
for nylon, while the cycle numbers for acetate in both cases were
very low, 2 and 19 respectively. This indicates that the testing
conditions were not severe enough for nylon (since an unduly long
time, approximately one hour, was necessary for a single test)
while they were, on the other hand, too severe for acetate since
rupture occurred in a few seconds. Textile fibers with such great
differences in abrasive behavior must be tested under different
testing conditions if the tests are to be performed in a reasonable
length of time. A way must be found, of course, which permits
valid comparison of cycle numbers obtained at different severities
for the evaluation of different fibers.

The severity of attrition was varied by changing the pressure
and tension exerted on the yarns, and also by changing the bundle
size (the number of strands in the yarn bundle).

Tests at varied pressures were performed on yarn bundles of
nylon and acetate multifilaments. Figure 8 shows that although a
higher pressure decreases the cycle numbers at break, an increase
of pressure (within the practicable limits of the tester) does not
markedly influence the severity of the test.

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*The relative tension of the acetate bundle was diminished by
increasing the number of yarn strands (from 27 to 108) instead of
reducing the tensioning load which remained constant. This was
necessarily connected with a much lower actual tension (0.17 g/gx)
for acetate than for nylon (0.68 g/gx).

TABLE I

FLEX ABRASION OF NYLON AND ACETATE UNDER IDENTICAL CONDITIONS

	Nylon Multifilament 100/40/2.5	Acetate Multifilament 100/40/2.5	
Yarn fineness, gx	111	111	
Tenacity at break, g/gx	5.45	1.25	
Elongation at break, %	21.4	24.3	
Number of yarn strands in the bundle	27	27	108
Overall fineness of the yarn bundle, gx	2997	2997	11988
Actual tension, g/gx	0.68	0.68	0.17
Relative tension, % of ultimate	13	55	14
Cycle numbers at break	6199	2	19
Relative cycle numbers	1000	0.3	3.3
Time of abrasion in a single test	51 min 35 sec	1 sec	10 sec

Tester: Stoll–Quartermaster abrasion tester with square-edged steel bar.
Rate: 120 double strokes per minute.
Stroke Length (bar): 0.5 in.(1.27cm).
Tensioning Load: 4.5 lb (2041 g).
Pressure: 1.0 lb (454 g).
Atmospheric Conditions: 70 F, 65% R. H.

FIG. 8
INFLUENCE OF YARN PRESSURE ON CYCLE NUMBERS

○ 18 NYLON (Type 300) MULTIFILAMENTS (III gx.) AT A YARN TENSION OF 4.5 lb.

● 54 ACETATE MULTIFILAMENTS (III gx.) AT A YARN TENSION OF 0.5 lb.

CYCLE NUMBER AT BREAK

PRESSURE LOAD ON ABRASION HEAD (lb.)

INFLUENCE OF YARN TENSION ON CYCLE NUMBERS

FIG. 9

SPUN NYLON YARN (DURHAM) VISCOSE MULTIFILAMENT ACETATE MULTIFILAMENT
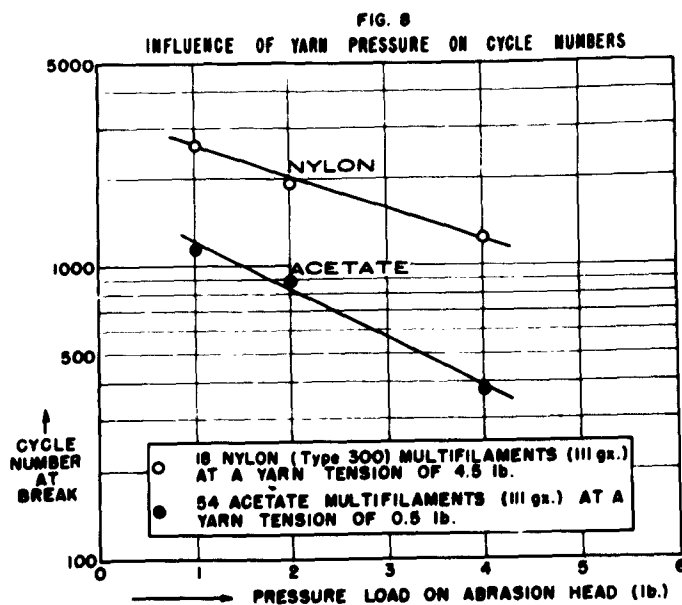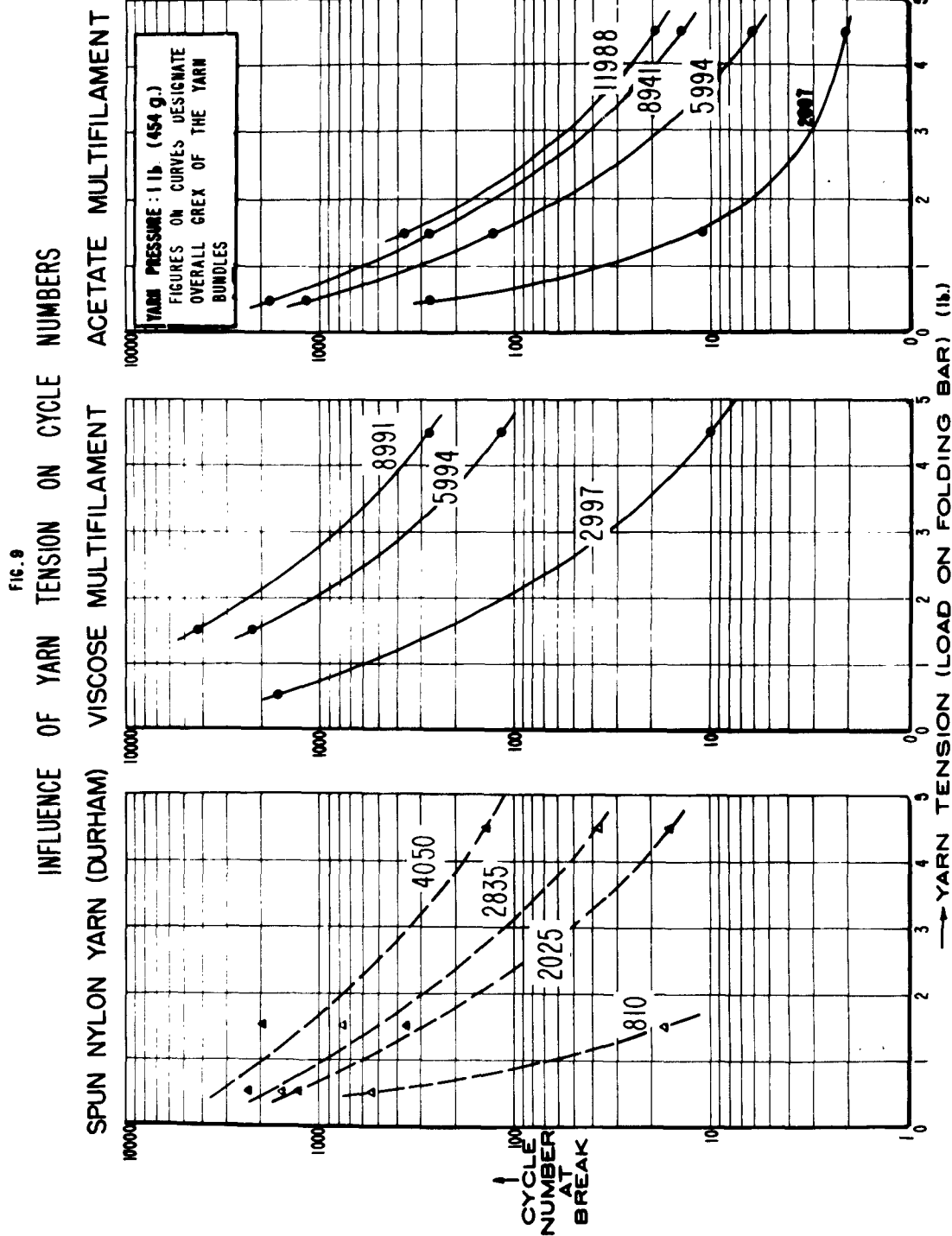
This can be better accomplished by increasing the tension. Tests at varied yarn tensions were made on yarn bundles of different total grex (containing different numbers) of a spun nylon yarn and of viscose and acetate multifilaments.* An essential decrease of the cycle numbers is observable in Figure 9 at higher tensions, indicating the considerably increased severity of the abrasion. A similar decrease of cycle numbers at increasing tensions has already been observed by Matthes and Keworkian [8] as shown in Figure 10. In these tests two loops of a staple viscose yarn of varied coarseness were abraded against each other using the T. H. Aachen yarn abrasion tester. When a larger number of yarn strands or a coarser yarn is abraded, more abrasive work is required for rupture and consequently higher cycle numbers appear for all the fibers demonstrated in Figures 9 and 10.

FIG. 10

RELATIONSHIP BETWEEN YARN TENSION AND CYCLE NUMBERS (MATTHES & KEWORKIAN, 1943)
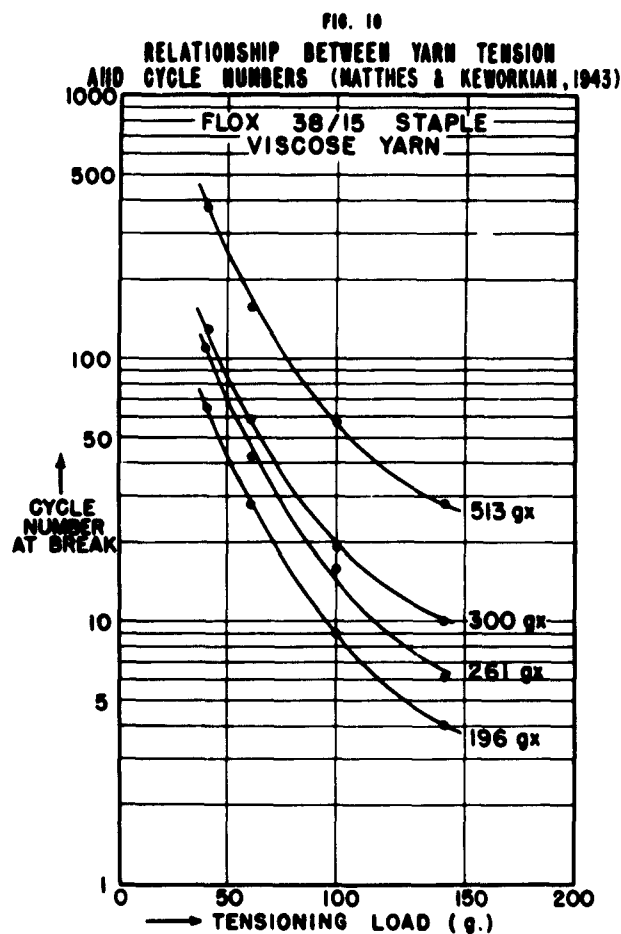
*Characteristics of these yarns are listed in Table IV (Nos. 5, 8, and 20).

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FIG. II
INFLUENCE OF BUNDLE SIZE (GREX) OF NYLON YARNS ON CYCLE NUMBERS
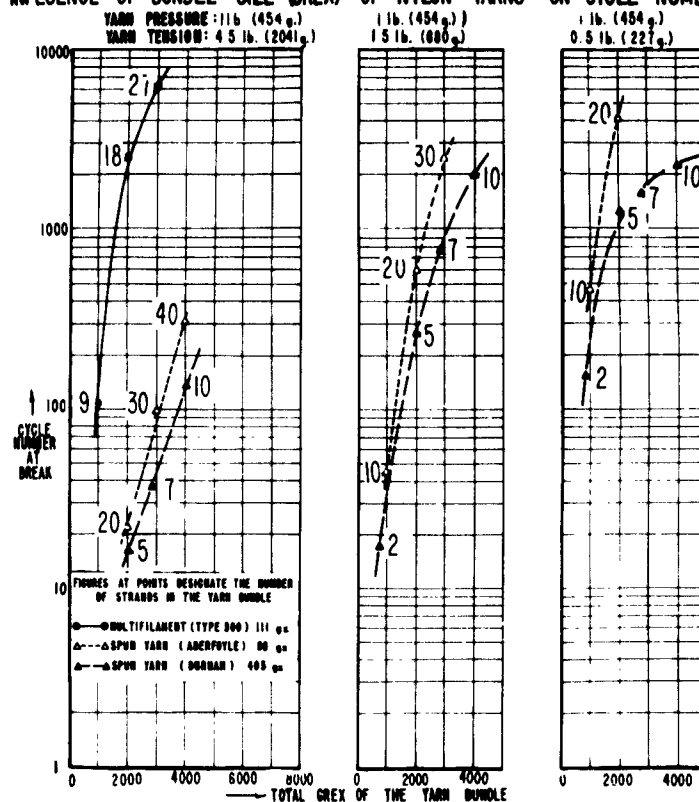
TABLE II

FLEX ABRASION TESTS OF NYLON YARNS AT VARIOUS TENSIONING LOADS

Yarn Bundle		4.5 lb (2041 g) Tensioning Load			1.5 lb (680 g) Tensioning Load			0.5 lb (227 g) Tensioning Load		
		Tension		Cycle numbers at break	Tension		Cycle numbers at break	Tension		Cycle numbers at break
Number of yarn strands	Total grex	Actual g/gx	Relative % of tenacity at break		Actual g/gx	Relative % of tenacity at break		Actual g/gx	Relative % of tenacity at break	
MULTIFILAMENT (TYPE 300) NO. 1*										
9	999	2.04	37	107						
18	1998	1.02	19	2500						
27	2997	0.68	13	6199						
60/1 STAPLE YARN (ABERFOYLE) NO. 3*										
10	980				0.70	32	45	0.23	10	462
20	1960	1.05	47	22	0.35	16	597	0.12	5	4131
30	2940	0.70	32	98	0.23	10	2458			
40	3920	0.52	24	310						
30/2 STAPLE YARN (DURHAM) NO. 5*										
2	810				0.84	35	17	0.28	12	154
5	2025	1.01	42	16	0.34	14	268	0.11	5	1238
7	2835	0.72	30	37	0.24	10	769	0.08	3	1540
10	4050	0.51	21	136	0.17	7	1979	0.06	2	2246

TEST CONDITIONS: Yarn pressure 1 lb (454 g); other conditions as in Table I except where otherwise specified.
*Table IV and Figure 16.

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The influence of yarn bundle size is better shown in
Figure 11 and Table II where the abrasion of nylon multi-
filaments and of two nylon staple yarns (60/1 Aberfoyle and
30/2 Durham)* is demonstrated in three sections representing
three different severities of attrition. The severity was
diminished here by reducing the tensioning load without
changing the pressure. The curves of Figure 11 show that the
cycle numbers increase very rapidly by increasing the yarn
bundle size. The exponential relationship fully justifies the
evaluation procedure suggested by Schiefer and Werntz, [11]
namely, comparison of logarithms of cycle numbers instead of
numerical values of cycle numbers in laboratory abrasion tests.
The evaluation of these authors is more realistic than comparison
of "sky-rocketing" cycle numbers so far as the substance destroyed
is taken into consideration. The curves shown in Figure 11 also
provide the cycle numbers at break for any required bundle size,
as well as the bundle size which fails in any cycle numbers within
the limits of tests performed. A graphical extrapolation on such
curves will be used in a new testing technique described later
(see page 16) in order to obtain the fiber grex abraded in a
constant number of cycles selected as comparison level for the
abrasion of various fibers. It can been seen on the curves of
Figure 11 that an approximately linear relationship exists between
the logarithm of cycle numbers and numerical values of yarn grex
for points sufficiently close to each other on the curves. These
observations are in full agreement with the discussed results of
Matthes and Keworkian [8] obtained on different sizes (196-513
grex) of a viscose staple yarn tested at varied severities of
attrition as demonstrated in Figure 12.

Numerical data of the curves demonstrated in the three
sections of Figure 11 are shown in Table II where yarn tension
appears as tensioning load (in lb and g), as actual tension
expressed in g/gx tenacity values, and as relative tension
expressed in percentage of the tenacity at break. At each
severity a progressively increased number of yarns was abraded
corresponding to yarn bundle sizes from roughly 1000 to 4000
total grex.** Since the tensioning load remained unchanged in
each section, the increase of the bundle size (total grex)
necessarily reduced the actual and relative tensions exerted

*Characteristics of these yarns are listed in Table IV (Nos. 1,
3, and 5.

**Nylon multifilament bundles could not have been abraded at 1.5
and 0.5 lb tensioning loads without increasing excessively the
cycle numbers at break and the time necessary for each test.

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FIG. 12

RELATIONSHIP BETWEEN YARN SIZE AND CYCLE NUMBERS
(MATTHES & KEWORKIAN 1943)

FLOX 38/15 STAPLE VISCOSE YARN
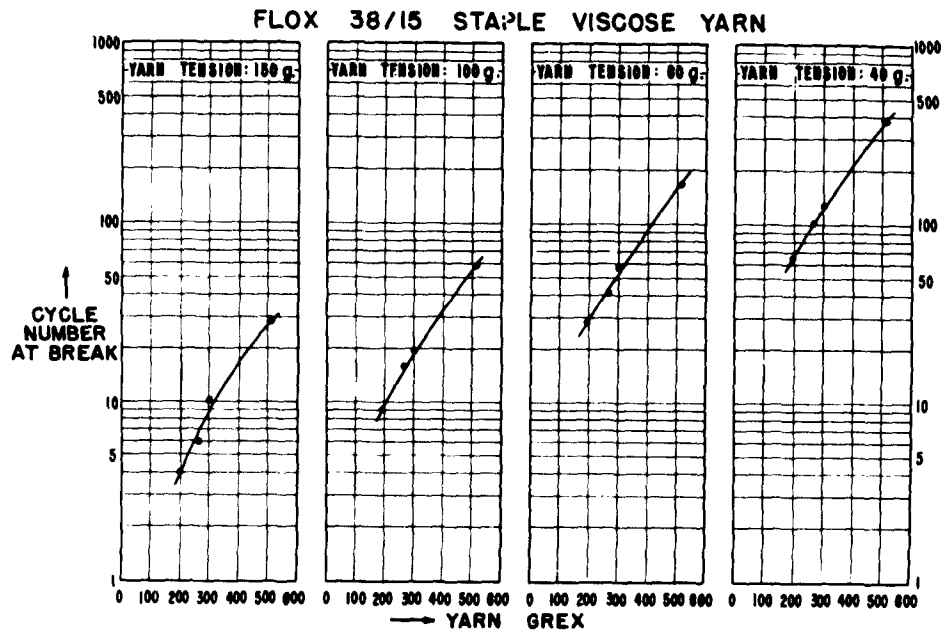
on the yarn bundle, thus also diminishing the severity of the tests. In view of this fact, cycle numbers at break increased considerably with increasing grex of the yarn bundle.

In contrast to the tensioning load which remains constant during the abrasion, the actual and relative tensions listed in Table II apply only to the beginning of the test. They increase with the attrition of the yarn bundle, first slowly and then rapidly until the tenacity at break is reached at the end of the test. Rupture occurs, therefore, in these abrasion tests partly as a result of an excessive tension applied to the yarns.

By changing the pressure and tension exerted and the number of yarn strands in the yarn bundle, it is possible to arrive at conditions under which all commercial textile fibers can be abraded using the above-described technique in a reasonable number of cycles (between 100 and 1000) and length of time (from 1 to 8 minutes) for each test.

A quantitative comparison of different fibers is possible from a series of such tests if conducted under identical testing conditions. Figure 11 shows, for instance, that nylon multifilaments which could be tested only at the highest severity, have a much greater abrasion resistance than the two staple yarns. The 60/1 Aberfoyle staple yarn appears slightly more resistant than the 30/2 Durham staple yarn at all three tensions. The Aberfoyle yarn is a single yarn, it is finer, has a finer staple, is weaker, less extensible but more elastic than the Durham yarn.* It will be shown later that high elasticity of yarns is critical for good resistance to abrasion. Conducting such abrasion tests as shown for these nylon yarns is, of course, time-consuming. Moreover, a quantitative comparison of fibers tested under different severities is not possible. Even slight changes in the testing conditions affect the cycle numbers at break considerably and in a complex way which is certainly not uniform for all textile fibers. Therefore, it is difficult to transform cycle numbers observed under different testing conditions into comparable values.

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*The characteristics of these two yarns are as follows:

	30/1 Aberfoyle	60/2 Durham
Staple fineness	1.7 gx	3.3 gx
Staple length	1.5 in. (3.8 cm)	1.5 in. (3.8 cm)
Yarn fineness	98 gx	405 gx
Twist multiplier	3.24	3.29/2.58
Breaking tenacity	2.21 g/gx	2.40 g/gx
Extensibility	22.0 per cent	31.7 per cent
Recoverable elongation	79 per cent	66 per cent
Elastic energy (of total)	68 per cent	52 per cent

TESTING PROCEDURE FOR OBTAINING ABRASION DAMAGE

A new t.iting and evaluation method has been used in
this study in order to measure quantitatively the resistance
to abrasion of various textile fibers with great differences
in abrasive behavior. In these tests the destructive action
(cycle number) is kept constant, and the abrasion damage is
measured. This is expressed by the grex or yarn fineness
(weight per unit length) destroyed. The abrasion damage
obtained for various fibers is then correlated to that
suffered by nylon multifilaments and is denoted as relative
abrasion damage. The relative abrasive damage is, therefore,
a dimensionless number which indicates how much more grex of
a fiber is abraded at failure than of a highly resistant nylon
multifilament exposed to the same conditions. This comparison
eliminates some inadequacies of the testing procedure carried
out under conditions that are necessarily arbitrary.

It was found suitable to compare the abrasive damages of
commercial fibers (under the above-described testing conditions)
after 120 cycles which require only one minute for a single
abrasion test. A low cycle number was selected for comparison
merely on grounds of economic considerations. Comparison at
lower cycle numbers than 120 can hardly be recommended, but
there is no objection to using higher numbers such as 240 or
even 1200. Tests at higher cycle numbers will be appropriate
for less severe abrasive actions, e. g., if a folding bar with
round edges, or lower pressures and tensions, or fewer cycle
numbers per minute are used. Tests at higher cycle numbers
will also be necessary if the rate of abrasion must be
investigated. Any change in the comparison level and in the
severity of tests will, of course, affect the abrasion results
obtained and in some cases it might even affect the relative
ranking of fibers with similar resistance to abrasion.

It would be difficult to find directly the fiber grex
that fails in 120 cycles. This value can be obtained in a
simple way, however, if yarn bundles containing varied numbers
of yarns are tested which require cycle numbers close to 120
cycles for rupture. The fiber grex abraded in 120 cycles can
then be obtained graphically from these tests, assuming a linear
relationship between the logarithms of cycle numbers and numer-
ical values for the total grex of the yarn bundle which fails.
This assumption is valid for points which lie sufficiently
close to each other on the curve representing the relationship
between cycle numbers and grex abraded (as shown in Figures 11
and 12), and there can be no objection to such an extrapolation
if carried out within reasonable limits.

-16-

In the testing procedure yarn bundles in two or even three different sizes were abraded for each material, at least one of them requiring less, and another more, than 120 cycles for rupture. The closer the cycle numbers approximate 120 cycles, the less is the possibility of misrepresentation due to the extrapolation and to other distorting factors. Therefore, only yarn bundles requiring more than 20 or less than 600 cycles were tested and evaluated. It is not difficult to estimate the proper number of yarn strands to be tested in the yarn bundle if the destructive action of the tester, and the fineness, structure, and abrasive behavior of the yarn are known approximately. Otherwise, the suitable bundle size must be found by trial and error. This can be carried out easily in a surprisingly short time. The testing of five identical bundles to obtain an average is accomplished within few minutes and represents a considerable saving of time if compared to conventional abrasion tests. Although the abrasion of two or even three bundle sizes increases the time necessary for performing a complete set of tests, this additional time is still moderate, and is unavoidable if reliable results are expected.

It is obvious that abrasion tests should be performed under identical conditions in order to obtain directly comparable results. Any deviations from an accepted standard procedure affect the results and sometimes in such a way that it cannot be accounted for correctly. Unfortunately, testing conditions could not be kept identical in any respect for all commercially available yarns. They were abraded, however, under as similar conditions as feasible. Multifilaments and staple yarns with fairly similar form factors and in yarn sizes between 98 and 456 grex* were tested. The number of strands in the yarn bundle was never less than 8 or more than 80, and the overall grex of the yarn bundle was in all but a very few cases between 1000 and 12,000 grex. These precautions were necessary to avoid marked distortions of results.

Nylon multifilaments (which served as a basis in correlating the abrasion damages) had to be tested under a rather severe destructive action using 4 lb (1814 g) pressure and tension.

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*Although yarn size is generally expressed in denier for multifilaments and by the "yarn number" in cotton or worsted counts for staple yarns the universal grex yarn numbering system was adopted to designate the yarn size. This permits the direct comparison of yarn finenesses for all the materials tested.

Most yarns could not be abraded under the same conditions, within the above limitations. Therefore, the severity of the abrasion was diminished by decreasing the yarn pressure and tension simultaneously to 2, 1, and 0.5 lb without changing other parameters. This measure made it possible to test even fibers with very low inherent abrasion resistance within the above restrictions. Damages observed at these milder testing conditions were then transformed by calculation to make them comparable with the damage of nylon obtained at the highest severity. Viscose multifilament was selected as a reference fiber to detect quantitatively the decreased attrition brought about by the diminished pressure and tension. The medium abrasive behavior of viscose multifilament makes it convenient for testing at all four severities (4, 2, 1, and 0.5 lb pressure and tension) without deviating from the above requirements.

Details of the testing and evaluation procedure are demonstrated in Table III and Figure 13 for nylon, viscose, and acetate multifilaments of 111 gx (Nos. 1, 8, and 20, respectively, Table IV). Yarn bundles consisting of 8, 10, and 14 nylon yarn strands were abraded at 4 lb yarn pressure and tension. From these tests 1120 grex was obtained by extrapolation* as the fineness of nylon abraded in 120 cycles. (In the lower left part of Figure 13, 1120 grex value appears at the intersection of the vertical line for 120 cycles with the slightly inclined line representing the relationship between the grex abraded and the cycle numbers at break.) Much coarser yarn bundles of viscose (50 and 60 multifilaments) had to be tested at the same severity in order to obtain cycle numbers at break close to 120. An extrapolation gave 6200 grex as abrasion damage of viscose in 120 cycles. The ratio between the grex values of viscose and nylon (6200 and 1120) is 5.53 and represents the relative abrasion damage of viscose compared to nylon. This figure indicates that 5.53 times more (by weight or grex) viscose was abraded than nylon in the abrasion tests performed.

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*In the graphic extrapolation preference was given to cycle numbers close to 120. The cycle numbers for 10 yarn strands in Table III were obtained on different days, and they indicate the rather low reproducibility observed. Figure 13 shows, however, that the grex value of fiber damage (at the comparison level of 120 cycles) is only slightly affected by such great variations.

FIG. 13
DEMONSTRATION OF THE TESTING AND EVALUATION PROCEDURE
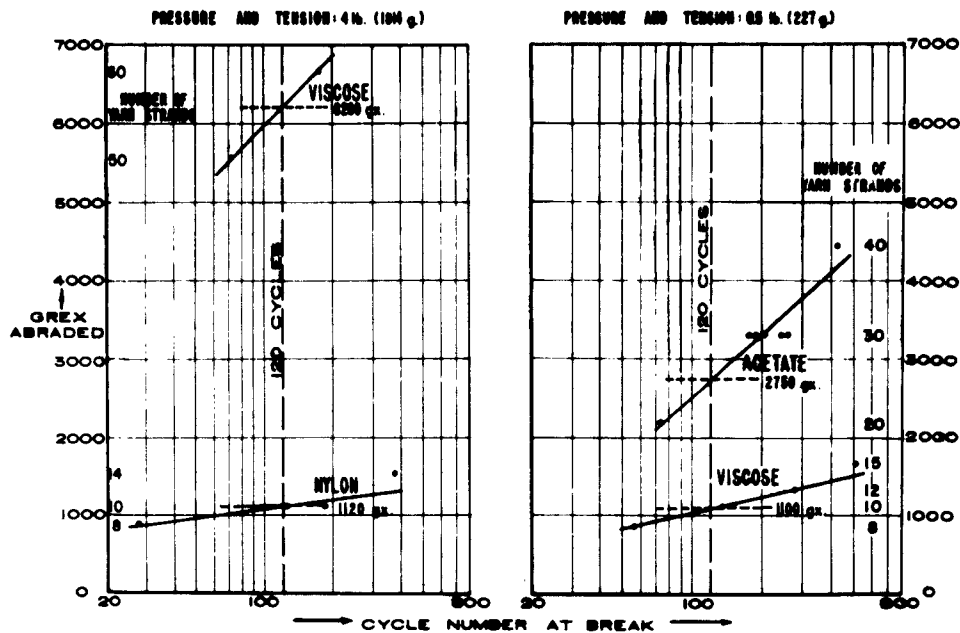
TABLE III

PROCEDURE FOR TESTING THE ABRASION DAMAGE OF NYLON, VISCOSE, AND ACETATE MULTIFILAMENTS*

Sample	Yarn Bundle		Yarn tension and pressure 4 lb (1814 g)			Yarn Bundle		Yarn tension and pressure 0.5 lb (227 g)		
	Number of yarn strands	Total grex	Actual tension g/gx	Relative tension % of tenacity at break	Cycle numbers at break	Number of yarn strands	Total grex	Actual tension g/gx	Relative tension % of tenacity at break	Cycle numbers at break
Nylon Type 300 (No. 1 in Table IV)	8	888	2.05	38	28					
	10	1110	1.63	30	96					
	10	1110	1.63	30	123					
	10	1110	1.63	30	186					
	14	1554	1.17	21	381					
Extrapolated*		1120	1.63	30	120					
Viscose (No. 8 in Table IV)	50	5550	0.33	19	72	8	888	0.26	15	56
	60	6660	0.27	16	179	10	1110	0.20	11	136
						12	1332	0.17	10	276
						15	1665	0.14	8	506
Extrapolated*		6200	0.29	17	120		1110	0.21	12	120
Acetate No. 20 in Table IV						20	2220	0.10	8	73
						20	2220	0.10	8	75
						30	3330	0.07	5	177
						30	3330	0.07	5	189
						30	3330	0.07	5	207
						30	3330	0.07	5	245
						30	3330	0.07	5	262
						40	4440	0.05	4	424
Extrapolated*							2750	0.08	6	120

Test Conditions: As in Table I, except when otherwise specified.

*Demonstrated in Figure 13.

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The acetate multifilaments could not be tested under such severe conditions without increasing the number of yarn strands excessively. They were abraded under markedly milder conditions, using only 0.5 lb pressure and tension. Acetate yarn bundles consisting of 20, 30, and 40 strands were abraded and 2750 grex abrasion damage was obtained in 120 cycles. Viscose was also tested as a reference fiber under these milder conditions using 8, 10, 12, and 15 yarn strands. The abrasion damage of viscose in 120 cycles was now only 1100 grex.* A comparison of the abrasion damages of acetate and viscose (2750 and 1100 grex) shows that 2.50 times more acetate than viscose was abraded at the low severity of 0.5 lb pressure and tension. Multiplication of this ratio, 2.50, by the relative abrasion damage of viscose obtained at the high severity, 5.53, gives the relative abrasion damage of acetate as 13.83 times higher than that of nylon at the high severity of 4 lb yarn pressure and tension. This value indicates that the same destructive action abrades acetate 13.8 times as much as nylon. The calculated value of the relative abrasion damage of acetate is, of course, an approximation because the translation of a damage under mild conditions into one at high severity is not necessarily exactly the same for acetate as for viscose. It is known that abrasion proceeds at different rates in fibers. It can be assumed, however, that the behavior of viscose at varied severities represents with fair approximation an average progression of abrasion from which that of the other fibers tested might not deviate too significantly.

The tensions applied to the yarn bundles in the tests and at the extrapolated comparison level of 120 cycles are shown in more detail in Table III. The actual and relative tensions decrease markedly in each series of tests with increasing number of yarn strands in the bundle as an obvious consequence of increasing the bundle size (total grex) at a constant tensioning load. Besides this the actual and relative yarn tensions at the comparison level diminish considerably from nylon to viscose to acetate according to their decreasing abrasion resistance.* No doubt the decreased tensions affect the abrasion damages observed since a lower yarn tension corresponds to less severe attrition. Therefore, a lower abrasion damage is obtained in these tests for fibers with low resistance than for highly resistant fibers. The tests performed favor in some sense fibers with low resistance and they penalize highly resistant fibers. This causes some distortion of the abrasion damages observed which is unavoidable for tests carried out at constant pressure and tensioning loads. This distortion is not serious, however, so long as one realizes its origin and

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*The significance of actual and relative yarn tensions will be discussed later (see pages 27, 28).

consequences. Without this distortion the abrasion damage of poorly resistant fibers would become even higher than obtained in this study and the "spectrum" of abrasion damages (as demonstrated in Figures 14 and 16) would appear extended in the direction of higher abrasion damages.

Abrasion tests could be performed at equal actual pressure and tension values (g/gx), but this would require a marked change in the pressure and tensioning load for each different bundle size. They could also be performed at a fixed percentage of the breaking tenacity (i. e., at identical relative tensions) but this would mean that testing fibers with different breaking tenacities and bundles of varied fineness would differ in the actual tensions (g/gx) and in the tensioning loads applied. These modifications in the testing and evaluation method also distort test results. They might have some advantages under certain circumstances but they are not superior to the procedure followed in this study in which the damage of different materials at a standardized pressure and tensioning load is compared. No testing and evaluation process is conceivable in which viscoelastic fibers with different properties can be abraded under conditions identical in every respect. The various fibers, for instance were not abraded in this study either at a constant actual or at a constant relative strain. Strain was not taken into consideration at all, although the elongation of fibers at the start of the tests (as a result of the tension applied) and also the elongation of yarn bundles during the flexing procedure influence test results. The abrasion of yarn bundles was normalized only with respect to stress (correctly with respect to the tensioning load at the beginning of the test), and this excludes simultaneous normalization with respect to other parameters (e. g.,actual or relative tension, strain, recovery, etc.).

It is remarkable that the actual and relative tension values of viscose multifilaments at the comparison level of 120 cycles remain similar in the two series of tests demonstrated in Table III and Figure 13 despite the considerable differences in the pressure and tensioning loads applied. It is obvious that if these tensions at varied severities are substantially different from each other, markedly different abrasion values can be obtained for the same yarn.

RELATIVE FLEX ABRASION DAMAGES OBSERVED

The new testing procedure was followed in evaluating 27 yarns (9 multifilaments, 18 staple yarns) representing 14 different textile materials with a wide range of abrasion resistance. Figure 14 and Table IV demonstrate the tests performed under four different severities using yarn pressures and tensions of 4, 2, 1 and 0.5 lb. Although data are shown for clarity of presentation in Figure 14 under only one pressure for each yarn (with the exception of viscose multifilament, No. 8, and the two Orlon staple yarns, Nos. 22 and 23), most of the yarns were actually abraded under two and in some cases even three severities as shown in Table IV. Tests with cycle numbers at break markedly different from 120 were also omitted.

Abrasion behavior of various fibers is demonstrated by more or less inclined straight lines in Figure 14. They are parts of curves showing the relationship between grex abraded and cycle numbers. The steepness of the lines indicates the rate of the attrition. The inclination increases (with some exceptions*) in each section with increasing abrasion damage and it shows a faster progression of attrition for less resistant yarns. The rate of abrasion is by no means identical for all fibers. Matthes [7] has already found in his yarn abrasion tests that the cycle numbers of glass fibers decreased rapidly with increasing tension while those of other fibers decreased only moderately. This author demonstrated the abrasion behavior of five fibers (multifilaments of viscose, acetate and glass fiber, and staple yarns of viscose and wool) by straight lines plotting the logarithm of "specific tensions"** against the logarithm of cycle numbers at break (Figure 15A).*** The abrasion lines have different inclinations and they can be represented by the equation

$$s\sigma^x = \text{Constant},$$

where s is the cycle number at break, σ a term for tension and the exponent x a term for flexing. The abrasion lines connect points corresponding to tensile strength (on the ordinate) and to cycle numbers at break of samples without tension (on the abscissa). Obviously the latter value reflects the resistance to flexing.
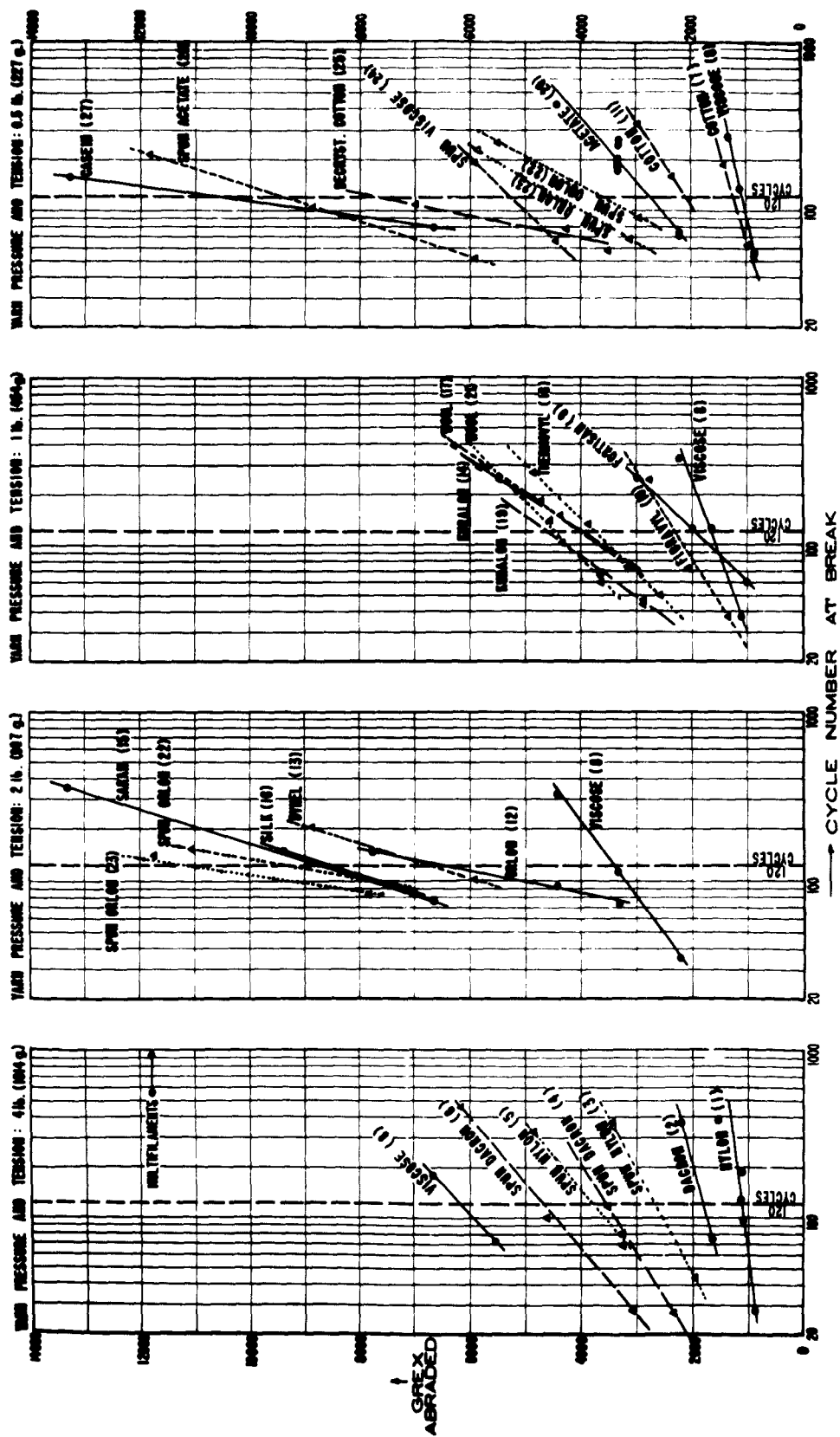
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*For example, Orlon acrylic fiber multifilaments (No. 12) in the second, and Fortisan (No. 9) in the third section.

**Specific tension (kg/sq nm) is comparable to actual tension values (g/gx) used in this study.

***Figure 4 of reference [7].

FIG. 14

FLEX ABRASION TESTS PERFORMED ON DIFFERENT TEXTILE MATERIALS

— CYCLE NUMBER AT BREAK

TABLE IV

ABRASION DAMAGE OF VARIOUS TEXTILE FIBERS

	1	2	3	4	5	6	7	8	9
	Designation	Characteristic				Abrasion Damage Observed (grex abraded in 120 cycles)			
						Tested at a yarn pressure and tension of:			
No.		Yarn Type	Yarn Fineness in gx	Tenacity at Break in g/gx	Elongation at Break in %	4 lb. (1814g)	2 lb. (907g)	1 lb. (454g)	0.5 lb. (227g)
1	Nylon Type 300, 100/40/2.5	Multifilament	111	5.45	21.4	1120*			
2	Dacron Polyester Fiber 100/40	Multifilament	111	5.28	18.1	1800*			
3	Nylon 60/1 (Aberfoyle)	Staple Yarn	98	2.21	22.0	2650*			
4	Dacron Polyester Fiber 20/1 (Dixie)	Staple Yarn	295	2.42	38.0	3550*	1850		
5	Nylon 30/2 (Durham)	Staple Yarn	405	2.40	31.7	3750*			
6	Dacron Polyester Fiber 60/2 (Phaar)	Staple Yarn	309	2.78	39.7	4700*			
7	Cotton 50/1	Staple Yarn	118	1.88	5.7		2950		1200*
8	Viscose 100/40	Multifilament	111	1.75	15.7	6200*	3400*	1700*	1100*
9	Fortisan 90/120/3	Multifilament	100	6.95	5.6			1950*	1150
10	Fibravyl 75/1 (Rhodia)	Staple Yarn	138	1.41	18.9			2300*	1600
11	Cotton 20/1, Untreated	Staple Yarn	297	1.47	9.1		3600		2100*
12	Orlon Acrylic Fiber 100/40	Multifilament	111	4.34	15.9	11500	6250*		
13	Dynel 20/1	Staple Yarn	296	1.10	27.5	11750	6650*		
14	Kuralon 40/1 (Omni)	Staple Yarn	146	1.44	20.0			3900*	2050
15	Saran 200/12/5	Multifilament	222	1.88	15.3		8600*	3400	1950
16	Silk 100/132	Multifilament	117	4.02	21.8		8555*	3850	1900
17	Wool 28.4/1	Staple Yarn	315	0.84	33.2			3950*	2480
18	Thermovyl 30/1 (Rhodia)	Staple Yarn	324	0.29	100.0			3750*	2600
19	Kuralon 80/2 (Omni)	Staple Yarn	144	2.44	11.2			4600*	2450
20	Acetate 100/40/2.5	Multifilament	111	1.25	24.3			4250	2750*
21	Wool 45/2 (WC 3)	Staple Yarn	456	0.77	34.0		8300	4450*	
22	Orlon Acrylic Fiber 16/1 (Champlain)	Staple Yarn	369	1.86	13.7		9300*		3600*
23	Orlon Acrylic Fiber 15/1 (Newman)	Staple Yarn	391	1.38	24.0		11250*		4400*
24	Viscose 20/1	Staple Yarn	296	1.26	16.2				5250*
25	Cotton 20/1, Decrystallized	Staple Yarn	350	1.53	17.3				7600*
26	Acetate 20/1	Staple Yarn	296	0.88	21.9			13750	9350*
27	Casein 300/40	Multifilament	333	0.78	41.0				10500*

Test Conditions: As given for Table I except when otherwise specified.

Remarks: *Demonstrated in Figure 14

TABLE IV (CONTINUED)

ABRASION DAMAGE OF VARIOUS TEXTILE FIBERS

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Actual Yarn Tension in g/gx**				Relative Yarn Tension in Percent of Ultimate**				Relative Yarn Abrasion Damage						
									Tested at a yarn pressure and tension of:				Average ***	Range ± %	Ratio Between Multifilament and Staple Yarn ****
	Tested at a yarn pressure and tension of:														
No.	4 lb	2 lb	1 lb	0.5 lb	4 lb	2 lb	1 lb	0.5 lb	4 lb	2 lb	1 lb	0.5 lb			
1	1.63				30				1.00				1.0		
2	1.01				19				1.61				1.6		
3	0.68				31				2.37				2.4		1:2.4
4	0.51	0.49			21	20			3.17	3.02			3.1	3	1:1.9
5	0.48				20				3.34				3.3		1:3.3
6	0.39				14				4.20				4.2		1:2.6
7		0.31		0.19		17		10		4.80		6.04	5.4	11	
8	0.29	0.27	0.27	0.21	17	15	15	12	5.53	(5.53)	(5.53)	(5.53)	5.5		
9			0.23	0.20			3	3			6.36	5.78	6.1	5	
10			0.20	0.14			14	10			7.46	8.06	7.8	4	
11		0.25		0.11		17		8		5.84		10.54	8.0	29	
12	0.16	0.15			6	3			10.28	10.22			10.3	3	
13	0.15	0.14			14	13			10.48	10.88			10.7	2	
14			0.12	0.11			8	7			12.70	10.34	11.5	10	
15		0.11	0.13	0.12		6	7	6		14.00	11.06	9.86	11.6	18	
16		0.11	0.12	0.12		3	3	3		13.88	12.50	9.58	12.0	18	
17			0.12	0.09			14	11			12.80	12.46	12.6	1	
18			0.12	0.11			36	33			12.2	13.10	12.7	4	
19			0.10	0.09			4	4			15.0	12.3	13.7	9	
20			0.11	0.08			9	6			13.8	13.8	13.8	0	
21		0.11	0.11			14	13			13.5	14.5		14.0	4	
22		0.10		0.06		5		3		15.15		18.2	16.7	9	1:1.6
23		0.08		0.05		6		4		18.3		22.2	20.3	10	1:2.0
24				0.04				3				26.4	26.4		1:4.8
25				0.03				2				38.2	38.2		
26			0.03	0.02				3			44.6	46.7	45.7	2	1:3.3
27				0.02				3				52.6	52.6		

Test Conditions: As given for Table I except when otherwise specified.
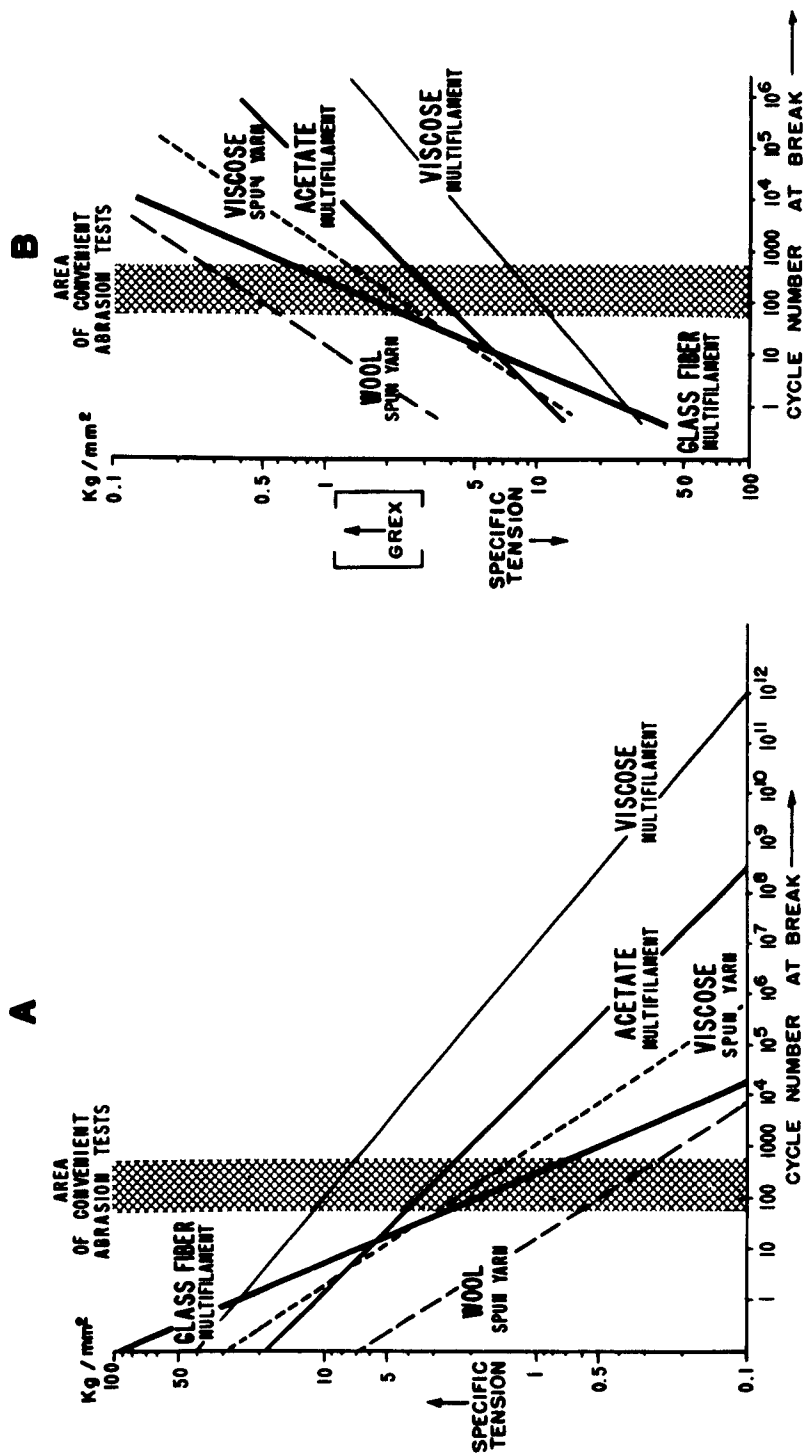
Remarks: **At the (extrapolated) comparison level of 120 cycles
***Demonstrated in Figure 16
****Demonstrated in Figure 17

EVALUATION OF YARN ABRASION TESTS PERFORMED BY MATTHES (1947)

FIG.15

If the five abrasion lines close to the area of "convenient abrasion tests" (for cycle numbers between 80 and 800) of Figure 15A are replotted with tension values inversed a pattern is obtained as shown in Figure 15B. This pattern is remarkably similar to that demonstrated in the four sections of Figure 14 since a decrease in tension is equivalent in these tests to an increase in grex. The inclination of the abrasion lines increases also in Figure 15B with decreasing abrasion resistance of the fibers tested. The abrasion line for glass fibers has an exceptional steepness (like those of Orlon and Fortisan multifilaments in Figure 14) and it reflects the faster progression of attrition in flexing this fiber.

In Figure 14 viscose multifilament as the reference fiber appears in all four sections. The steepness of the viscose lines decreases with diminishing severity of the tests performed, indicating again the slower progression of abrasion under less severe attrition. In the second section of Figure 14 the distance on the vertical line representing 120 cycles (between the intersection of the viscose line and the two fairly parallel lines for spun Orlon acrylic fiber) represents the range of damages which can be conveniently detected at this severity within the previously specified restrictions. The distance between the viscose and the spun Orlons appears shortened in the fourth section of Figure 14 and the range of damages which can be tested at this low severity is markedly extended.

Details of the abrasion tests performed are listed in Table IV where the fibers tested appear in order of increasing inherent abrasion damage observed. Data in columns 6-9 show clearly that the abrasion damage (the grex abraded in 120 cycles) of all fibers diminishes essentially with decreasing severity. The rate of reduction is roughly identical to that of the tensioning load. The relative abrasion damages obtained at different degrees of severity (columns 18-21), however, do not differ markedly from each other indicating that the described evaluation method is basically correct. Deviations from the average values (columns 22 and 23) are small in most cases, the greatest being ± 29%. This is remarkable in view of the great variations of cycle numbers observed in individual abrasion tests.

Although actual and relative yarn tensions varied in the tests performed using different bundle sizes, these values are listed in columns 10-17 for that (extrapolated) bundle size which fails in 120 cycles. Data of columns 10-13 show that the actual tension (g/gx) of the fibers tested decreased markedly with increasing relative abrasion damage of the fiber. The tests performed thus favor fibers with low abrasion resistance. Nevertheless,

the actual tension remains almost unaffected for each fiber*
in tests at different severities despite the considerable
differences in the tensioning load applied.

A similar though less consistent trend is observable when
the relative tensions of the fibers tested are compared in
columns 14-17.** It is noteworthy that in these tests the ratio
between the highest and lowest relative tension (31 and 2 per
cent) is markedly less than that for actual tensions (1.63 and
0.02 g/gx). It is obvious that yarn abrasion should be tested
at relatively low tensions since otherwise the response observed
will be that to tension rather than to abrasion. On the other
hand, the tension should not be so low that an excessive time is
necessary for testing, especially when highly resistant fibers
are abraded.

The actual and relative tension values shown in Table IV
were not preselected but appeared spontaneously as a result of
the four tensioning loads applied to the yarn bundles. They
represent a fortunate and workable compromise between the con-
flicting requirements for tension limits.

The average values of relative abrasion damages (column
22, Table IV) are demonstrated graphically in Figure 16 for
multifilaments and for staple yarns separately. A logarithmic
scale was selected here to show the small differences in yarns
with low abrasion damage (high abrasion resistance) and also
the great differences among the textile fibers.

The quantitative data obtained permit the classification
of textile fibers into three main groups. The first group
(with relative abrasion damages below 5) contains multifila-
ments and staple yarns of nylon and Dacron polyester fiber
corresponding to excellent resistance to abrasion. The
majority of textile fibers belong in the second group (relative
abrasion damages between 5 and 25) with medium damages. The
last group (values above 25) comprises the few materials with
high damage or poor resistance to abrasion, and includes staple
yarns of viscose, decrystallized cotton, and acetate, and casein
multifilament.

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*Exceptions: Nos. 7, 10, and 11.

**Apparently the values shown for Nos. 2, 9, 12, and 16 are
too low, while those for Nos. 17, 18, and 21 seem to be too
high. No explanation can be given for these deviations from
the rule.

FIG. 16

# RELATIVE ABRASION DAMAGE OF VARIOUS TEXTILE FIBERS

MULTIFILAMENTS

No.
1. NYLON TYPE 300 ;100/40/25·1
2. DACRON POLYESTER FIBER 100/40·
8. VISCOSE 100/40·
9. FORTISAN 90/120/3·
12. ORLON ACRYLIC FIBER 100/40·
15. SARAN 200/12/15·
16. SILK 100/132·
20. ACETATE 100/40/2.5·
27. CASEIN 300/40·

→ RELATIVE ABRASION DAMAGE
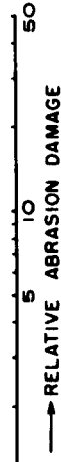
STAPLE YARNS

No.
3. NYLON 60/1 (ABERFOYLE)·
4. DACRON POLYESTER FIBER 20/1 (DIXIE)·
5. NYLON 30/2 (DURHAM)·
6. DACRON POLYESTER FIBER 60/2 (PHAAR)·
7. COTTON 50/1·
10. FIBRAVYL 75·
11. COTTON 20/1 UNTREATED·
13. DYNEL 20/1·
14. KURALON 40/1·
17. WOOL 28 4/1·
18. THERMOVYL 30/1·
19. KURALON 60/2·
21. WOOL 45/2·
22. ORLON ACRYLIC FIBER 16/1 (CHAMPLAIN)·
23. ORLON ACRYLIC FIBER 15/1 (NEWNAN)·
24. VISCOSE 20/1·
25. COTTON 20/1 DECRYSTALLIZED·
26. ACETATE 20/1·

→ RELATIVE ABRASION DAMAGE
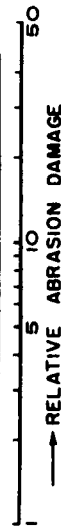
Among the new synthetic fibers only Dacron polyester
fiber is comparable to nylon. The damage of Orlon acrylic
fiber by abrasion is markedly higher and not very different
from that of viscose. The behavior of the synthetic staple
yarns Fibravyl, Dynel, and Kuralon is remarkable. These
fibers are considerably more affected by abrasion than staple
nylon and Dacron polyester fiber, but appreciably less than
staple viscose and acetate. The abrasion damage of cotton
yarns is also fairly low except when the cellulose is present
in a decrystallized form. [15] No doubt the form factors and
finish of the yarns tested affect the results. Great differ-
ences in the form factors of multifilamentous and staple yarns
were avoided, and no special finishes were used, so that the
results would not be unduly affected thereby. Different
staple yarns of the same fiber material* had different form
factors and were obtained mostly from different sources, but
their relative abrasion damages were very similar as compared
to the large differences observed among the various textile
materials.

Although the ranking of multifilaments with respect to
abrasion damage is essentially the same as that of staple
yarns, the relative abrasion damage of spun yarns was always
found to be higher than that of multifilaments. The individual
staple fibers sticking out from the yarn surface can be easily
pulled out or cut through. This causes a loosening and untwist-
ing of the yarns which additionally increases the attrition if
tensional and bending forces act upon the yarn. The ratio
between the relative abrasion damages observed for multifilaments
and staple yarns (column 24, Table IV) varied from 1:1.6 (for
16/1 Orlon acrylic fiber) to 1:4.8 (for viscose) as demonstrated
in Figure 17.

FIG 17

RATIO BETWEEN RELATIVE ABRASION DAMAGES
OF MULTIFILAMENTS AND STAPLE YARNS

No.
3 NYLON 60/1 (ABERFOYLE)· · · · · · · ·
5 NYLON 30/2 (DURHAM)· · · · · · · · ·

4 DACRON POLYESTER FIBER 20/1 (DIXIE)·
6 DACRON POLYESTER FIBER 60/2 (PHAAR)·

22 ORLON ACRYLIC FIBER 16/1 (CHAMPLAIN)·
23 ORLON ACRYLIC FIBER 15/1 (NEWHAM)· ·

24 VISCOSE 20/1 · · · · · · · · · · · · ·

26 ACETATE 20/1 · · · · · · · · · · · · ·

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1        2     3    4  5
RELATIVE ABRASION DAMAGE
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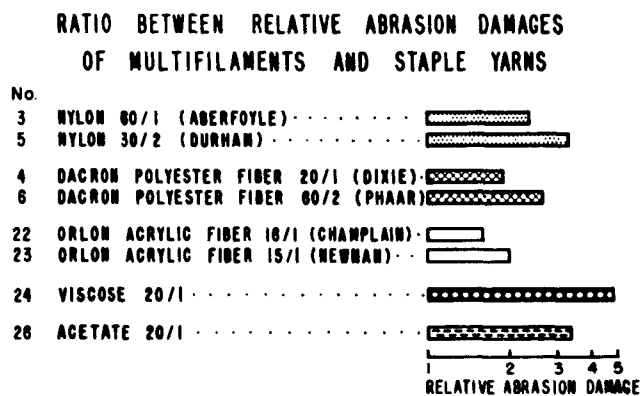
*Staple yarns of 60/1 and 30/2 nylon, 20/1 and 60/2 Dacron poly-
ester fiber, 50/1 and 20/1 cotton, 40/1 and 80/2 Kuralon, 28.4/1
and 45/2 wool, and 16/1 and 15/1 Orlon acrylic fiber.

A higher abrasion damage of staple yarns has also been observed by other authors. Matthes [7] found a lower resistance to abrasion of viscose, cuprammonium, and acetate staple yarns as compared to multifilaments using the T. H. Aachen yarn abrasion tester. Lower abrasion life was also observed by Hicks and Scroggie [5] for staple yarns than for multifilaments in flat abrasion tests of viscose yarns performed on the Taber tester.

The difference is slight between the relative abrasion damage observed for the two samples of nylon, Dacron polyester fiber, Kuralon, and Orlon acrylic fiber staple yarns as demonstrated in Figure 16. It is also noteworthy that with the exception of Kuralon, the less extensible and more elastic sample of each pair suffered the lower damage despite the fact that considerably lower total energy was necessary for its rupture. In the case of nylon and Dacron polyester fiber the more resistant sample had also a slightly lower tenacity at break. The superior elasticity of the yarns with lower abrasion damages is revealed by the lower relative values of their unrecoverable elongation component at the breaking point and of their unrecoverable work component listed in Table V.* The higher flex abrasion damage of the less extensible, markedly stronger and more elastic 80/2 Kuralon yarn is apparently the result of some "over stretching" which makes the fiber less resistant to forces transverse to the fiber length (flexing, shear).

FACTORS PREVENTING ABRASION DAMAGE

It will be worthwhile to discuss some factors preventing abrasion damage. According to Hamburger [4,6] good abrasion resistance (low damage) depends more on high energy necessary for rupture than on high tenacity at break. It is obvious that abrasion will be influenced, not so much by the work absorbed in the first deforming process (total energy of rupture) as by the work absorbed during repeated deformations. This work is manifested in the elastic energy or the recoverable portion of the total energy (the sum of immediately recoverable and creeping recoverable work component). It is also revealed in the work absorption of fibers after repeated deformations (mechanical conditioning). It is obvious that the energies necessary for breakdown in compression, bending, and shear are as important for the evaluation of flex abrasion as the energy

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*The actual values of the recoverable energies are not listed in Table V. They were higher for the sample of each pair having the lower abrasion damage, except in the case of Kuralon.

TABLE V

THE ELASTIC BEHAVIOR OF STAPLE YARNS OF NYLON,

DACRON POLYESTER FIBER, ORLON ACRYLIC FIBER, AND KURALON

No. in Table IV	Designation	Relative abrasion damage*	Elongation at break in %	Relative values of elongation components at the breaking point			Total energy of rupture in g-cm/gx for 1 m fiber length	Relative values of work components (in % of total work)		
				Immediate elastic recovery	Delayed recovery	Unrecoverable		Immediately recoverable	Creeping recoverable	Unrecoverable
3	Nylon 60/1 (Aberfoyle)	2.4	22.0	20	59	21	20.2	13	55	32
5	Nylon 30/2 (Durham)	3.3	31.7	13	53	34	35.6	6	46	48
4	Dacron Polyester Fiber 20/1 (Dixie)	1.6	38.0	10	22	68	46.9	7	17	76
6	Dacron Polyester Fiber 60/2 (Phaar)	4.2	39.7	11	20	69	57.1	8	11	81
14	Kuralon 40/1 (Omni)	11.5	20.0	11	39	50	15.5	9	33	58
19	Kuralon 80/2 (Omni)	13.7	11.2	18	54	28	12.8	12	54	34
22	Orlon Acrylic Fiber 16/1 (Champlain)	16.7	13.7	19	55	26	14.8	12	59	29
23	Orlon Acrylic Fiber 15/1 (Newman)	20.3	24.0	16	34	50	22.9	10	31	59

*See column 22 of Table IV and Figure 16.

necessary for rupture in tension (when deforming factors act parallel to the fiber length). Unfortunately the former energies are unknown, but their relative ranking for textile fibers is presumably not greatly different from that in tension. Therefore, the elastic energies in tension (as revealed by the areas under the recoverable elongation of the stress-strain curves) permit at least a qualitative interpretation of abrasive damages in most cases.

Drawn nylon multifilaments require the highest energy for rupture among the known commercial textile fibers because of their high tenacity and high extensibility. The predominant part of this total energy is recoverable due to the high elasticity of drawn nylon. The tensile properties of high tenacity nylon multifilaments remain almost unaffected by mechanical conditioning [14] and consequently the work absorption does not diminish markedly if the deformation is repeated. This prevents the destruction of nylon by frequently repeated flex abrasion and is responsible for its extraordinarily low abrasion damage. On the other hand, staple nylon yarns usually have lower tenacity and elasticity but higher extensibility than multifilaments. They are, of course, markedly affected by mechanical conditioning which diminishes their energy necessary for rupture after the first deformation. An additional disadvantageous factor here is the looser yarn structure. The abrasive damages of staple nylon yarns are, therefore, higher than those of nylon multifilaments.

Wool yarns require a relatively high work for rupture despite their rather low tenacity. Their elastic behavior is also excellent and comparable to that of nylon. No appreciable loss in work absorption occurs in the repeated tensioning of wool. This explains the comparatively low abrasion damages observed for wool yarns. The properties favoring low damages by abrasion are not present to such a degree in casein. Therefore, casein suffers a much higher destruction than wool despite the similar tenacities and extensibilities of the two fiber types.

Extensibility is also a critical factor in flex abrasion. In frequent flexing of yarns around sharp edges a considerable elongation at the outside curvature of bent fibers takes place. If this elongation exceeds the extensibility of the fiber invariably rupture will occur. Although brittle fibers (glass fibers) may have low flex abrasion resistance, too high an extensibility favors flex abrasion damages, especially if the unrecoverable portion of the elongation (permanent set) is

considerable. In such cases (e. g., in acetate, decrystallized
cotton) the fiber length increases and the fiber cross-section
diminishes in each cycle. This in turn, causes stress concen-
trations and reduced resistance to forces acting perpendicularly
to the fiber axis (shear), resulting in rupture. It has been
shown that in the case of staple yarns of nylon, Dacron poly-
ester fiber and Orlon acrylic fiber, the less extensible and
more elastic samples suffered the lower abrasion damages.

The yarn surface, too, is no doubt an important factor
for abrasion damages. Finishes may prevent easy detachment of
single fibers particularly in staple yarns and also may harden
and smoothen out the yarn surface, thus reducing the friction.
On the other hand, finishes might stiffen yarns and prevent the
free mobility and yielding of single fibers in the yarn structure,
thus enhancing abrasion damages. All the above factors must be
taken into account in order to understand fully the damage of
textile fibers by abrasion.

REFERENCES

1. Anon., Textile Test Methods. Federal Specification CCC-T-191b (15 May 1951) Methods 4308, 5300, 5302, 5304, 5306, 5308, 7308; U. S. Government Printing Office, Washington 25, D. C.

2. ASTM Standards 1952. Part 7. - Tentative Methods of Tests for Abrasion Resistance of Textile Fabrics - ASTM Designation D 1175-51 T, p. 156-174, American Society for Testing Materials, Philadelphia, Pa., January 1953.

* 3. Backer, S., The Relation Between the Structural Geometry of a Textile Fabric and Its Physical Properties. Part II. The Mechanics of Abrasion. Textile Research J., 21, 453-468 (1951). TSR No. 61.

4. Hamburger, W. J., Mechanics of Abrasion of Textile Materials. Textile Research J., 15, 169-177 (1945).

5. Hicks, E. M., and Scroggie, A. G., Taber Yarn-Sheet Abrasion Tester. Textile Research J., 18, 416-423 (1948).

6. Kaswell, E. R., Textile Fibers Yarns and Fabric. Chapter 17, Abrasion and Wear Resistance, p. 295-346. Reinhold Publishing Corporation, New York, N. Y. 1953.

7. Matthes, M., Abrasion Tests on Yarns. Melliand Textilber., 28, 150-153 (1947).

8. Matthes, M., and Keworkian, A., The Relationship Between Abrasion Resistance and Twist of Yarns. Melliand Textilber., 24, 216-217, 249-254 (1953).

9. Ray, L. G., The Role of Synthetic Fibers in the Textile Industry of the Future. Textile Research J., 22, 144-151 (1952).

10. Schiefer, H. F., Fourt, L., and Kropf, R. T., Textile Testing in Germany. Part II. Serviceability Evaluation of Textiles. Textile Research J., 18, 18-38 (1948).

11. Schiefer, H. F., Werntz, C. W., Interpretation of Tests for Resistance to Abrasion of Textiles. <u>Textile Research</u> <u>J</u>., <u>22</u>, 1-11 (1952).

* 12. Stoll, R. G., An Improved Multipurpose Abrasion Tester and its Application for the Evaluation of the Wear Resistance of Textiles. <u>Textile Research</u> <u>J</u>., <u>19</u>, 394-415 (1949). <u>TSR No. 54</u>.

* 13. Stoll, R. G., Laboratory Evaluation of the Wear Resistance of Nonwoven Fabrics. <u>Am. Dyestuff Reptr.</u>, <u>40</u>, 305-311 (1951). <u>TSR No. 65</u>.

* 14. Susich, G., Mechanical Conditioning of Textile Fibers. <u>Textile Research</u> <u>J</u>., <u>23</u>, 543-572 (1953). <u>TSR No. 82</u>.

* 15. Susich, G., Decrystallized Cotton. <u>Am. Dyestuff Rptr.</u> <u>42</u>, 713-717 (1953). <u>TSR No. 79</u>.

16. Wagner, E., Abrasion Tests on Fibers, Yarns and Fabrics. <u>Die Bekleidung</u>, Nos. 2 and 4 (1950).

17. Walker, A. C., and Olmstead, P. S., Textile Yarn Abrasion Test. <u>Textile Research</u> <u>J</u>. <u>15</u>, 201-222 (1945).

18. Zart, A., Yarn Abrasion Tester. <u>Textil-Praxis</u>, <u>6</u>, 752-753 (1951).

* Also available in the form of Textile Series Reports as indicated by the <u>TSR No</u>. following the reference.

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